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Brief Communication: Technical Note

Preliminary Health Hazard Assessment: World Trade Center

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Abstract

Measurement of highly respirable asbestos aerosols inside intact building structures that are contaminated with residue produced during the collapse of the World Trade Center towers indicate a potential for elevated air concentrations of asbestos fibers under some conditions. The data suggest a greater potential for worker exposure to asbestos within building structures than previously reported for outdoor rescue and recovery work in the area around the World Trade Center. The data presented suggest that the unique set of conditions surrounding the fire and subsequent collapse of the WTC towers has created an asbestos fiber size distribution not previously encountered in an area of potential exposure to such a large segment of non-industrial population. The data illustrate the importance of careful selection and execution of routine laboratory methods for the identification and enumeration of airborne asbestos fibers.

Introduction

Shortly after the September 11, 2001 fire and catastrophic collapse of several office towers at the World Trade Center (WTC) in New York City, Health Hazard Assessments were conducted and continue to be conducted by public and private industrial hygiene investigators. Preliminary communications from investigators have consistently reported

finding no elevated hazardous aerosols or chemical vapors under outdoor conditions. To further investigate potential health hazards posed by site conditions near the WTC disaster site, a study of site conditions north of WTC Building #7 was conducted. This study measured a broad profile of potential hazards in surface residue and work zone air. Data related to asbestos content of surface residue and asbestos aerosols is reported. Data for other potential hazards has been presented separately.[1]

Reliable estimates of the nature and extent of asbestos-containing building materials installed at the WTC buildings is not available at this time. It is believed that asbestos-containing, spray-applied fire resistive coating was present on portions of structural steel on the lower floors of tower #1 (north tower) and elevator shaft structural steel, that asbestos-containing decorative finishes were originally applied to building lobbies and other public areas, and that up to 8.5 million square feet of vinyl asbestos floor tile was originally installed in WTC tower #1 and #2.

The energy and resulting force associated with the collapse of WTC tower #1 and #2 are consistent with the visual and tactile examination of the resulting debris and surface residue. For this reason, and to build a reliable foundation for assessing potential health risks associated with work that disturbs this surface residue, a particle characterization of the surface residue was conducted. Data from this characterization was used to design a study of workplace asbestos aerosols that included careful selection and execution of routine analytical methods to produce reliable data characterizing the workplace atmospheres.

Study Design & Methods

The study of surface residue focused on areas surrounding WTC Building #7 to the north (figure 4), east and west for a distance of four city blocks. A total of eleven specimens of surface residue were collected using separate and clean wooden spatulas (figure 3). Each specimen of surface residue was placed in separate 50mL conical plastic containers tightly closed with screw tops. Two specimens, (one from location #6 and one from location #10) were shipped by overnight mail to MVA, Inc. for particle size and compositional characterization. Eleven specimens were shipped by overnight mail to AMA Analytical Services, Inc. (Lanham, MD) for determination of asbestos content by PLM using EPA 400 point count quantitation. Specimen splits were also examined by HP Environmental to determine asbestos content by PLM using visual estimation quantitation.

Locations were selected for collection of surface residues by superimposing over the area of interest a semicircular grid with a diameter of eight city blocks (approximately 2,000 feet). Five radians were extended east, northeast, north, northwest and west from a focal point at the northern base of the WTC Building #7 rubble pile. Specimens of surface residue were collected at two points along each radian, the first at a distance of

[1] A complete set of data available from this Preliminary Health Hazard Assessment was presented on September 28, 2001 to the WTC Site Safety Committee and is available from Mr. David Collins, Director of Health and Safety, Turner Construction Company, NY, NY

approximately two city blocks from the focal point and a second approximately four city blocks along the radian. A graphical depiction of the sample location plan is presented in figure 2. A number was assigned to each location (as noted in figure 1) and this number is used as a descriptor for each sample of surface residue.

Subsequently, eleven air samples were collected within two building structures located near the collapsed WTC towers. Building structure A sustained limited damage but some areas of the lower floors were littered with paper debris and were coated with a layer of surface residue (see figure 5) . Building structure B sustained major damage with most areas littered with paper debris and coated with a layer of surface residue. Air samples within these two buildings were collected using 25 mm diameter, banded AHERA TEM cassettes (0.45 μm pore size mixed cellulose ester collection filter plus 5 μm pore size diffusion filter and cellulose support pad) (Zefon Analytical Accessories). Air sampling pumps (Gillian model/PN 800845) were calibrated at 2.0 liters per minute (LPM) and collection times varied with total air volumes ranging from 488 – 558 liters. Air sample locations are listed in Table 1. During air sample collection within Building A, routine loading and unloading of equipment was occurring in the loading dock area, routine office work was being performed within the 3rd floor office, debris removal associated with the repair of broken windows was occurring in the 11th floor office, and no work was being performed in the 36th floor office where windows were still intact. During air sample collection in Building B, no work was being conducted in the 3rd floor office space but contractors staged their various repair activities in the 3rd floor staging area. On upper floors (6th and 9th) of Building B, debris removal associated with preparations to repair broken windows was underway during air sample collection, with this activity concentrated on the 6th floor.

Asbestos content of the surface residue was determined by PLM using EPA method 600/R-93/116 dated July 1993 with visual volume estimation of the weight/weight percentage (w/w%) of asbestos. Quantitation of asbestos content was also determined independently for all samples of surface residue using the EPA 400 point count method.

Particle characterization was performed by MVA, Inc. in the following manner (Millette, 2001). The dust samples were characterized by both gravimetric measurement of sieve size fractions and by microscopical analyses. The samples were sieved using standard 4-inch diameter brass sieves (U.S. Standard Sieve Mesh #s 50 and 200). The gravimetric determinations were made of the following size fractions: >300μm, 75 - 300μm, and <75μm. The fractions were combined and examined by stereomicroscopy utilizing a Zeiss Stemi 2000 stereomicroscope having a magnification range from 6.5X to 47X. The components of the samples were then analyzed utilizing an Olympus BH-2 polarized light microscope (PLM) having a magnification range from 40X to 1000X. A visual estimate was made of the relative percentage by volume of loosely aggregated separable fibrous lint (hair + natural fibers + manmade fibers). Each identified constituent was rated as to whether it was "common" (consistently found throughout the sample) or "present" (detected but infrequently). The fine portions were analyzed by scanning electron microscopy (SEM) and transmission electron microscopy. The SEM analysis was done with a JEOL 6400 equipped with a Noran Voyager energy dispersive x-ray

analysis unit using both the secondary and back-scattered modes. Using the back-scattered electron (BE) mode, the sample was examined for particles that contained heavy elements. This procedure is useful in locating particles containing toxic metals such as lead and cadmium. Using the secondary electron (SE) mode, the sample was examined for particles that were consistent with asbestos fibers. X-ray elemental analysis (energy dispersive spectrometry (EDS) was performed on each particle located for further study by either the BE or SE scans. The fine (small) fraction of the samples were qualitatively analyzed with analytical electron microscopy (AEM) using a JEOL 1200, 100 kV scanning transmission electron microscope (STEM), equipped with a Noran EDS x-ray analysis system.

Airborne asbestos analysis was performed by Scientific Laboratories, Inc. in the following manner. The TEM air sample analysis method chosen for this specific application was the modified EPA Level II analysis Method following Yamate et al. (1984), chosen in order to provide the greatest flexibility in sample preparation and analysis. Heavy non-asbestos particulate loading encountered in many WTC air samples precludes analysis under the lower loading limitations of the EPA AHERA protocols which are optimized for clearance testing in essentially particle free atmospheres. Indirect preparation methods were applied when the Level II loading limitations were exceeded and the non-asbestos particulate obscured short, thin asbestos fibers (USEPA,, 1990). The possibility of bundle dispersion into single fibrils was expected to be of minimal impact due to the already highly dispersed nature of the asbestos aerosols observed in the WTC air samples (see figures 7 & 8). The air sample filters were gently collapsed using a DMF/acetic acid/DI water solution with mild heating on a slide warmer. The collapsed filters were subjected to the AHERA/EPA Level II calibrated plasma ashing procedure prior to deposition of a thin carbon support film. The carbon film covered, collapsed filter was placed onto a 200 mesh locator grid (Emicron, Inc.) and placed in a Jaffe wick DMF bath followed by an acetone rinse, Jaffe wick bath in order to remove the remaining MCE filter. The resulting direct preparation sample was analyzed by AEM in a JEOL 100-CX II TEM, equipped with an IXRF EDS x-ray analysis system. A total of 10 grid openings (5 on each of two grids) were analyzed. When the non-asbestos particulate loading was excessive, the particulate on a 1/4 segment of the filter was resuspended in DI water using mild agitation in a low power sonicator bath and an aliquot of the suspension was refiltered onto a 0.1 μm pore size MCE filter. The dried, indirect filter preparation was prepared as described previously.

PCM was performed on a portion of the original filters following the NIOSH 7400 method, Issue 2, 1994. The filters were collapsed using a VAP 300 acetone vaporizer (BGI Inc, Waltham, MA) and covered with a cover slip after application of a drop of triacetin. The prepared samples were analyzed on a calibrated Olympus CH-2 Phase Contrast Microscope at 400X. A total of 100 fields of view or 100 fibers in a minimum of 20 fields of view were counted on each sample. All fibers > 5μm long with an aspect ratio ≥ 3:1 were counted and assumed to be asbestos.

Findings

The particle size distribution of the surface residue at two locations, #6 and #10, are presented in Table 2. The data describe a residue that is dominated by very small particles with larger particles consisting primarily of mineral wool (fiber) aggregates.

The composition of the settled residue is presented in Table 3 and Table 4. The residue from both locations is uniform in its composition reflecting both the effect of fire and force applied to building materials and contents. Of note is the presence of small chrysotile asbestos bundles, both with and without attached binder.

The asbestos content determined by visual estimation and point counting is presented in Table 5. Asbestos was not observed in three samples, locations 3, 8 and 9. These locations are on a line approximately due north of WTC Building #7. All specimens on the 45° and 90° radians were found to contain asbestos by at least one analyst (see figure 6). The point counting method produced a range of positive values from <0.25 – 0.75%. This range is consistent with the compositional description provided by the particle characterization and not inconsistent with the visual estimation.

Airborne asbestos concentrations within two building structures that are damaged but standing and repairable are presented in Table 6. The transmission electron microscopy/ energy dispersive spectrometry (AEM) analysis detects a dominance of small, thin asbestos fibers less that or equal to 5 microns (≤5 μm) in length. Some longer fibers are also present but are generally one order of magnitude lower in concentration. Airborne asbestos concentrations measured by light microscopy are generally higher than concentrations reported using electron microscopy for fibers greater that 5 microns (>5 μm). The opposite relationship is found between airborne asbestos concentrations measured by light microscopy and those reported using electron microscopy for fibers less than or equal to 5 microns (≤5 μm). Comparisons for air samples which could be prepared and analyzed by both direct and indirect analysis indicates that for this matrix and set of circumstances the apparent asbestos fiber concentration may increase by as much as a factor of 10 for samples undergoing indirect preparation.

Discussion

Health risks associated with inhalation exposure to asbestos fibers have been an area of emphasis for public health practitioners for many decades (Lehman, 1936; Gilson, 1962; Landrigan, 1999; Anttila, 1993; Hillerdal, 1999; Kamp, 1999). During that time, toxicologists and epidemiologists conducted risk assessments and developed exposure criteria to manage and reduce known risk to appropriate levels for workers and the general population. In some cases these criteria have been promulgated by various governmental agencies as exposure limit standards. To evaluate worker and general population exposure to all airborne asbestos fibers, specialized laboratory methods have been used (Yamate, 1984; AHERA, 1987). As with all analytical methods, the various asbestos analytical methods have specific useful applications and limitations (Verma, 1995; Dement, 1990). Not all methods are suited to all applications and care must be

taken to understand each method's limitations as well as its reliability and suitability for a specific measurement set of conditions (Yamate, 1984; Chang, 1987)). Failure to correctly select the proper method, or failure to properly weigh the significance of resulting data, based on method limitations, may result in incorrect estimation of actual worker exposures and corresponding health risk. In this specific case it is particularly important since the particle size of the overloading non-asbestos material is of the same size as the fiber length of the thin asbestos fibers. The increased particulate load requires thicker carbon films for support which in turn compromises proper identification of the thinnest fibers by selected area electron diffraction (SAED).

The data presented in this report suggest that some surface residues deposited as a result of the fire and collapse of the WTC towers contain asbestos in the range of 0.25 – 0.75%. Additionally, the particle size of the surface residue is very fine (and dry), a condition not typically encountered during routine asbestos removal projects. Furthermore, the asbestos present at a concentration of approximately 1% is only a small fraction of the total mass of the surface residue, a residue that is a fine and dry powder. There is every indication, and it is reasonable to assume, that under commonly encountered conditions the components of the fine surface residue will become airborne and thus available for inhalation by workers. Under conditions where rapid dilution of the air does not occur, such as within building structures, it should be anticipated that very small asbestos fibers may become airborne and remain in the breathing zone of workers for extended periods. This condition will most likely occur inside buildings that have been contaminated with surface residues generated by the collapsed office buildings. This is evident in the data produced by the TEM method that detected asbestos fibers (asbestos structures) less than or equal to (≤) 5 μm in length at elevated concentrations in indoor air.

Airborne asbestos fiber concentrations estimated by Phase Contrast Microscopy (PCM) (NIOSH method 7400) are useful when particle size is large, non-fiber particle loading is light, and measured atmospheres are assumed to be dominated by asbestos fibers. In cases when fiber size is small and the concentration is low, PCM analysis may underestimate the asbestos fiber concentration. In contrast, when non-asbestos fibers dominate the atmosphere PCM analysis may overestimate the asbestos fiber concentration. For these reasons, application of PCM analysis is best suited for routine compliance screening of asbestos abatement practices and may not be applicable to investigations such as those conducted at the WTC site. A review of the comparison between PCM/TEM data presented in Table 6 illustrates the limitation of PCM analysis for investigations of atmospheres such as those encountered at the WTC site. Generally, health hazard assessors look at both TEM and PCM data when performing assessments with the understanding that TEM is recognized as providing the most complete data about exposure to asbestos fibers.

During the performance of testing for this preliminary health hazard evaluation, care was taken to perform all methods under strict adherence to published procedures. These procedures were appropriately modified when sample backgrounds exceeded the tolerance of the method. This level of care was a recognition of the unique condition presented by the composition and particle size profile of the surface residue as

determined prior to measuring airborne concentrations of asbestos. Similar care is advised for other analysts and investigators who are measuring and reporting worker and general population exposures to airborne asbestos fibers at or near the WTC disaster area.

The very short (typically <2 μm) and thin (<<0.25 μm) airborne asbestos fibers presented on a background of fine non-asbestos particulate (fibrous and non-fibrous) is a problem sample when conducting any airborne asbestos analytical method. Under the best of circumstances, a sample presenting with the combination of conditions, small thin fibers with a fine particulate background, requires the full attention of the analyst to produce and report reliable, unbiased data. It is critically important for the analyst to fully communicate all difficulties encountered when performing the analysis and to describe the potential influence any difficulty could have on the validity of the reported results.

It is equally important for investigators in the field to convey to the laboratory special conditions observed in the field when collecting air samples that could present an interference to the requested analytical method. If detection and measurement of short, thin asbestos fibers are important for the health hazard evaluation, or for compliance with regulatory standards, TEM analysis should be requested[2]. In addition, when short thin asbestos fibers are known to be present in the atmosphere, the influence of air sampling protocols on recovery of these fibers should be considered. Air filters submitted for transmission electron microscopy (TEM) should be polycarbonate or mixed cellulose ester filters with a 0.45 μm pore size, air sampling flow rates should be reduced to limit deep impaction of short thin fibers in filter media producing low fiber recovery, and laboratories should be instructed to employ method modifications if particle loading outside the tolerance limits of the method is encountered.

The set of data presented were developed as part of a preliminary health hazard evaluation conducted at the site of the collapsed WTC towers and buildings. The data represent the type of data required to make proper health hazard assessments. Preliminary site surveillance suggested that asbestos-containing residue produced during the collapse of the WTC structures would have particle dimensions not typically encountered in routine environmental hygiene practice. This hypothesis was tested and ultimately supported after conducting particle characterization with size differentiation on the surface residue. Subsequently, it was deduced from the character of the surface residue that aerosols within the damaged but standing building structures could be dominated by short, thin asbestos fibers. For this reason, special attention to air sample collection protocols, analytical method selection, together with informing analysts of known particle characteristics, produced the best available estimate of asbestos aerosol concentrations. It is recommended that investigators be alert to the uniquely fine particle component in surface residue that contaminates some sites near the WTC and take appropriate measures to insure that sample collection and analytical methods account for this condition.

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[2] Fibers less than 0.25 μm are not observed by NIOSH method 7400 (PCM) or reported by NIOSH method 7402 (TEM).

References

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Tables

Table 1. Air sample locations within two separate buildings near the World Trade Center.

Air sample #1	Building A, Loading dock
Air sample #2	Building A, Loading dock near freight elevator
Air sample #3	Building A, 3rd floor, office space east side
Air sample #4	Building A, 11th floor, office space east side
Air sample #5	Building A, 36th floor, office space, NE corner
Air sample #6	Building B, 3rd floor, office space
Air sample #7	Building B, 3rd floor, north staging area
Air sample #8	Building B, 6th floor, office space NE corner
Air sample #9	Building B, 6th floor, office space SW corner
Air sample #10	Building B, 9th floor, office space NE corner
Air sample #11	Building B, 9th floor, office space SW corner

Table 2. The particle size distribution of surface residue collected from location #6 and #10.

Size Fraction	Location #6 (w/w%) [1]	Location #10 (w/w%) [4]	Analytical Comments
>300μm	46% [2] (65% v/v%)	22% [5]	Tightly compacted fiber-rich aggregates
75-300μm	22%	37%	Mainly fibrous aggregates
<75μm	32% [3]	41% [6]	Gray powder .

1 No particles containing lead, chromium, cadmium, or mercury were observed.
2 Loosely aggregated, separable fibrous lint, primarily glass fibers.
3 Particles containing iron, copper and zinc were observed. Primarily fibrous glass & cement .
4 No particles containing chromium, cadmium, or mercury were observed.
5 No loosely aggregated, separable fibrous lint.
6 Particles containing iron, copper and lead were observed. Primarily fibrous glass & cement.

Table 3. Particle characterization of surface residue collected four blocks northeast of the northern base of WTC Building #7 (sample location #6).

- Construction debris
  - plaster
  - carbonate fragments
  - mica/vermiculite
  - glass fibers
  - chemically processed cellulose fibers
- Quartz grains
- Low-temperature combustion material [1]
- Hair
- Chrysotile asbestos fibers [2]
- Synthetic fibers
- Cellulose fibers [3]
- Insect parts
- Tar fragments

[1] includes charred wood fragments
[2] some with adhering carbonate binder, total estimated to comprise ≤1%
[3] cotton and paper

Table 4. Particle characterization of surface residue collected two blocks northeast of the northern base of WTC Building #7 (sample location #10).

- Construction debris
  - plaster
  - carbonate fragments
  - mica/vermiculite
  - glass fibers
  - chemically processed cellulose fibers
- Quartz grains
- Low-temperature combustion material[1]
- Hair
- Chrysotile asbestos fibers [2]
- Synthetic fibers
- Cellulose fibers [3]
- Insect parts
- Tarry fragments
- Plant fragments
- Rust flakes
- Sheet glass fragments

[1] includes charred wood fragments
[2] much with adhering carbonate binder, total estimated to comprise ≤1%
[3] paper

Table 5. Asbestos content of surface residue collected north of WTC Building #7.

Location	Asbestos Content (Visual)	Asbestos Content (Point Count)
#1– 4 Blocks east of Bldg. #7	>1%	<0.25%
#2– 2 Blocks east of Bldg. #7	>1%	ND
#3– Bldg. #7 Center	ND	ND
#4– 2 Blocks west of Bldg. #7	>1%	ND
#5– 4 Blocks west of Bldg. #7	>1%	0.5%
#6– 4 Blocks northeast of Bldg. #7	>1%	<0.25%
#7– 2 Blocks northeast of Bldg. #7	>1%	0.75%
#8– 2 Blocks north of Bldg. #7	ND	ND
#9– 4 Blocks north of Bldg. #7	ND	ND
#10– 2 Blocks northwest of Bldg. #7	>1%	0.75%
#11– 4 Blocks northwest of Bldg. #7	>1%	0.75%

Table 6. Airborne asbestos concentration in two building interiors near the collapsed WTC towers as measured by PCM and TEM.

Sample	Transmission Electron Microscopy EPA Level II, ≥ 3:1 particle aspect ratio				Phase Contrast Microscopy (NOISH Method 7400)
	Asbestos (>5 μm) Conc. (structures/cc)	Asbestos (0.5 - 5 μm) Conc. (structures/cc)	Total Asbestos (≥0.5 μm) Conc.		Asbestos Conc. (f/cc)
			(s/cc)	s/mm^2	
1	<0.007 (NSD)	0.255	0.255	369	0.049
2*	0.155	0.464	2.16	140	0.053
3	<0.007 (NSD)	0.117	0.117	170	0.046
4	<0.007 (NSD)	0.078	0.078	110	0.064
5	<0.007 (NSD)	0.008	0.008	10	<0.005
6*	<0.158 (NSD)	<0.158 (NSD)	<0.158	<10	0.062
7*	0.167	5.19	5.36	319	NA (1)
8*	<0.171 (NSD)	3.43	3.43	199	0.247 (2)
9*	0.346	5.01	5.35	309	0.536 (2)
10	<0.008 (NSD)	0.031	0.031	40	0.016
11	<0.008 (NSD)	0.047	0.047	60	0.034

NOTE ON LABORATORY REPORT (SCILAB-VA NYSDOH ELAP 10984)

* Indirect sample preparation performed.

(1) Analyst was unable to quantify fiber concentration because of overloading of particulate material on the filter.

(2) Moderate to heavy particulate matter is present on the filter which may obscure some fibers causing results with a low bias.

(3) NSD = No Asbestos Structures Detected.

Figures.

Figure 1. Surface residue sample location grid superimposed on a street map of lower Manhattan Financial District. Location #3 is at the northern foot of the debris pile for WTC Building #7. The WTC Tower 1 & 2 and Buildings 3, 4, 5 & 6 are located within the 16 acre square noted by the star marker. These collapsed structures are south of Building #7.

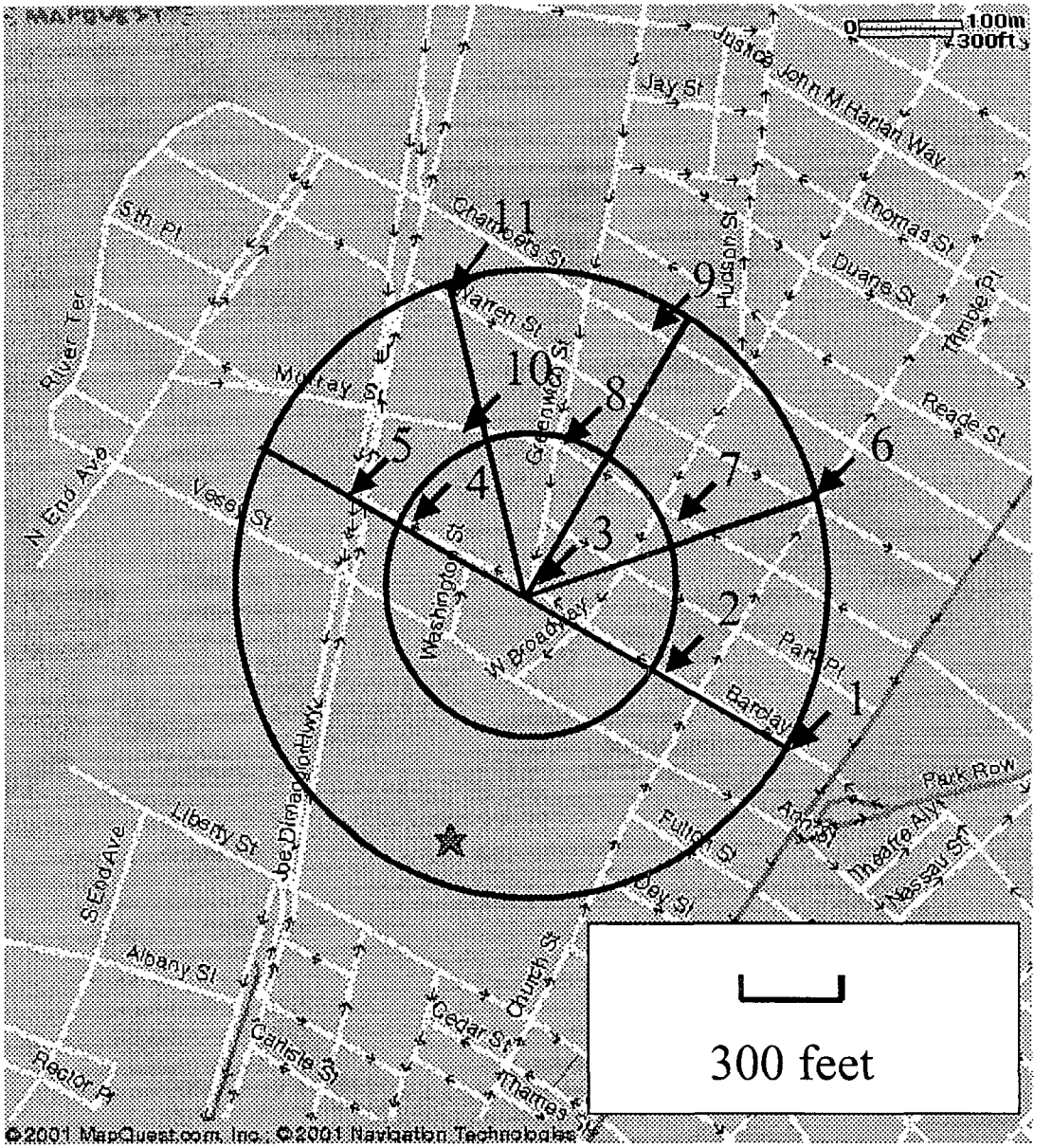

Figure 2. Surface residue sample location grid superimposed on a satellite photograph of lower Manhattan Financial District.

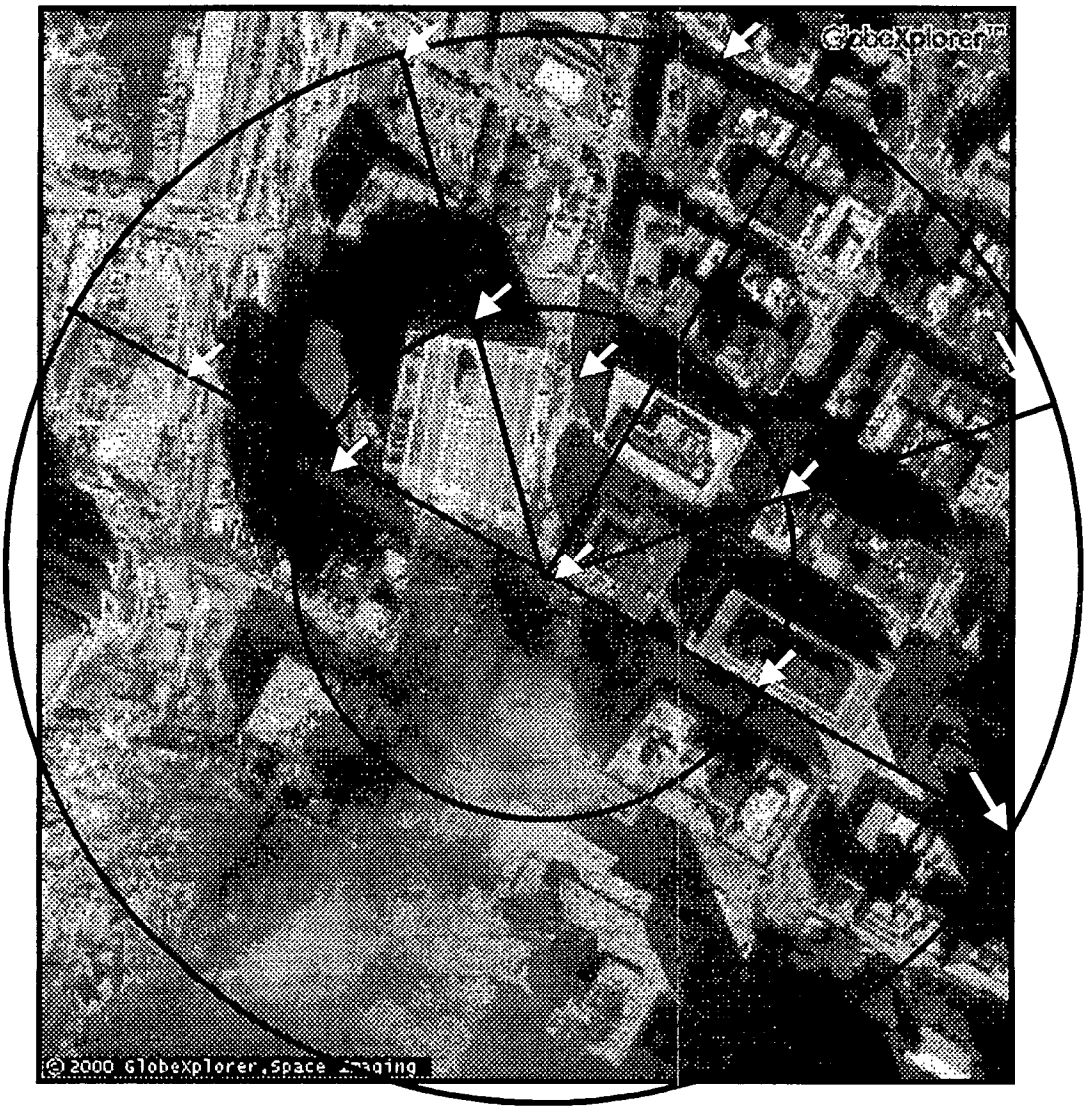

Figure 3. Surface residue sample location #8. Surface residue was collected from the windows and aluminum window ledges located in the picture foreground. This sample location is approximately two blocks north of WYC Building #7 visible in the photograph background as a rubble pile.

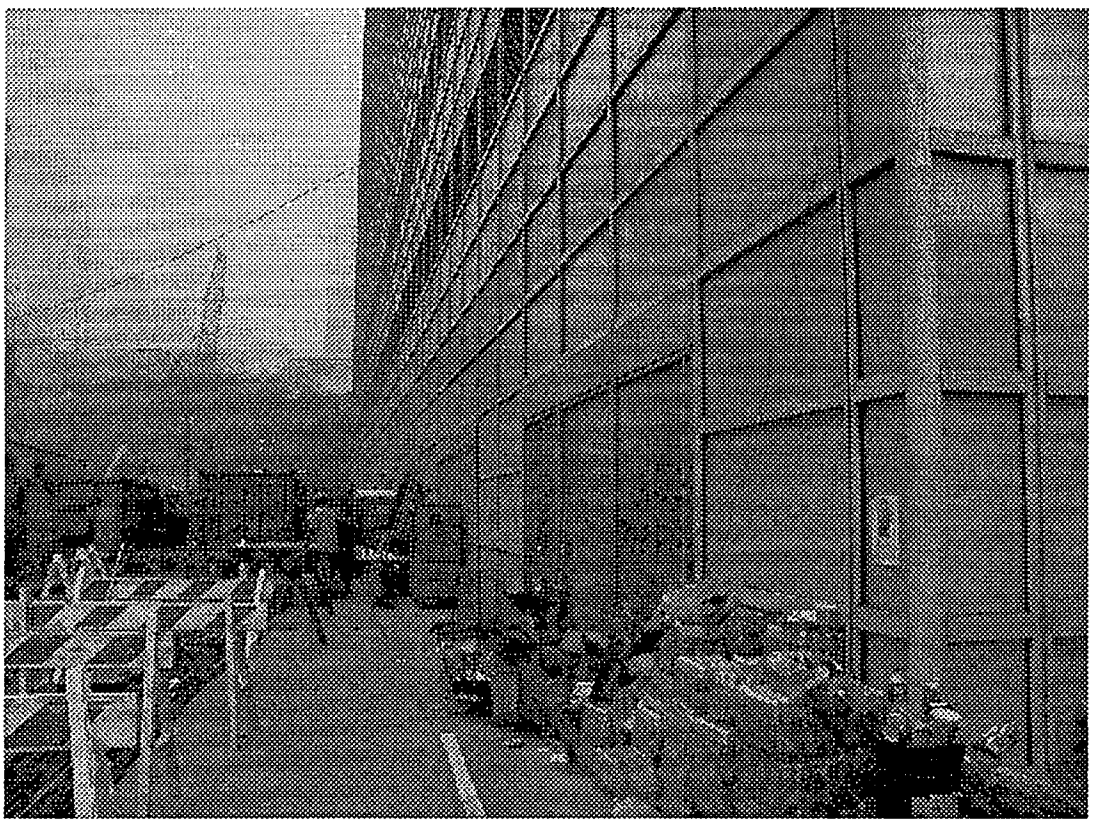

Figure 4. A close up view of surface residue sample location #8. Surface residue was collected from windows and aluminum window ledges.

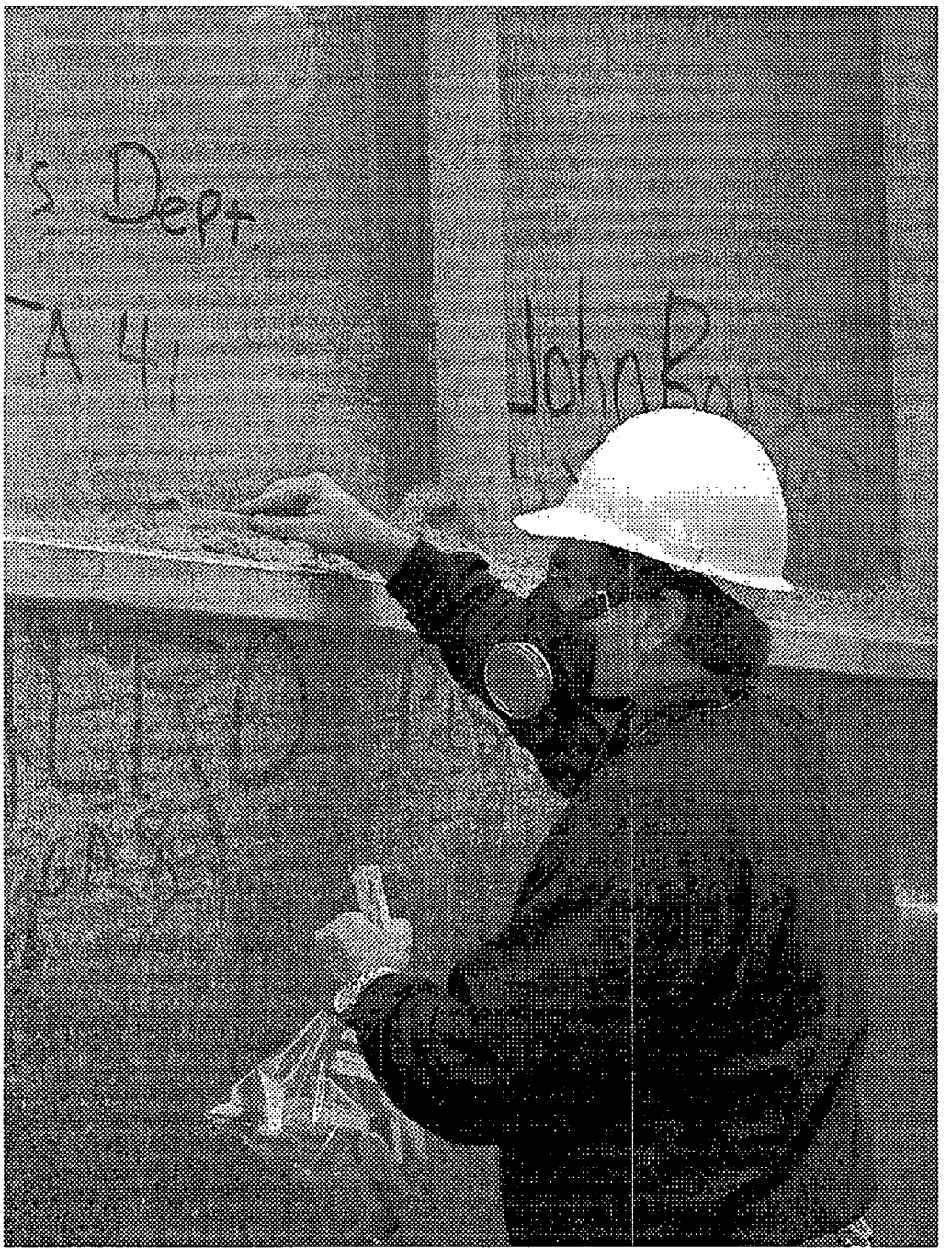

Figure 5. A view of a typical building interior for a structure near the WTC that suffered building skin damage (i.e. broken windows). A residue layer produced by the collapsed WTC buildings is present on substantial portions of interior surfaces.

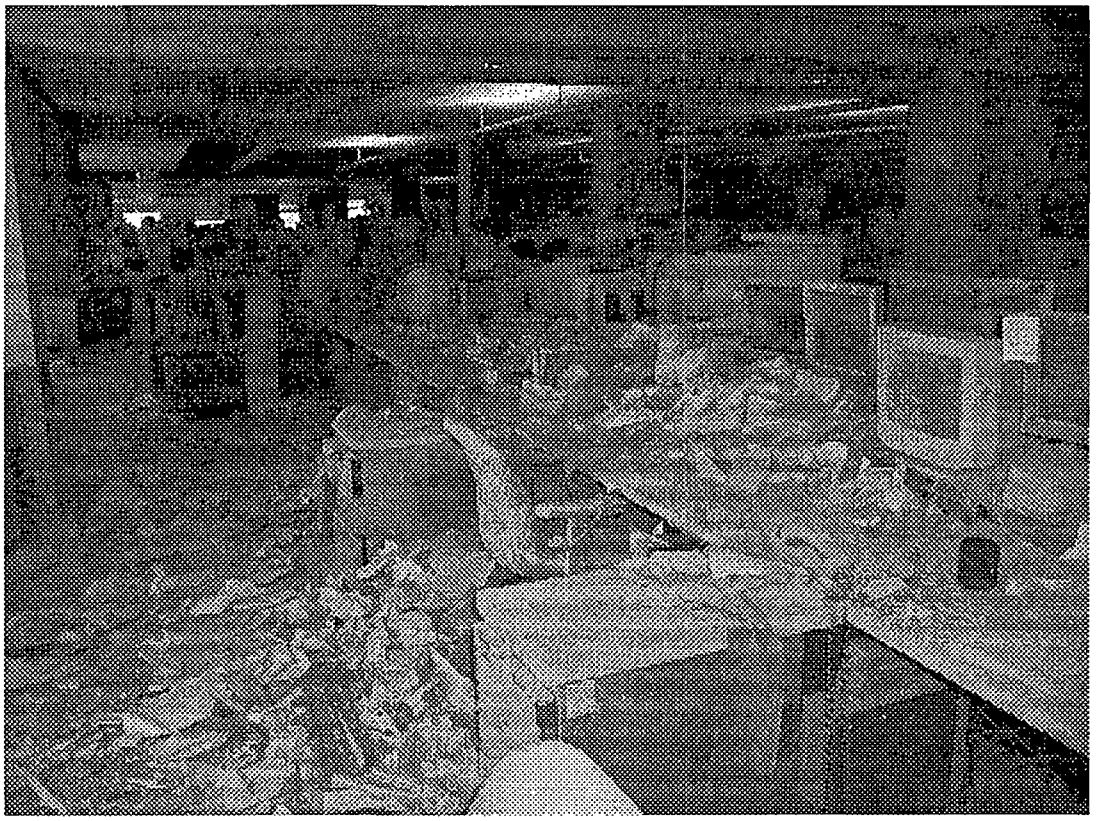

Figure 6. A diagram depicting asbestos content test results for surface residues.

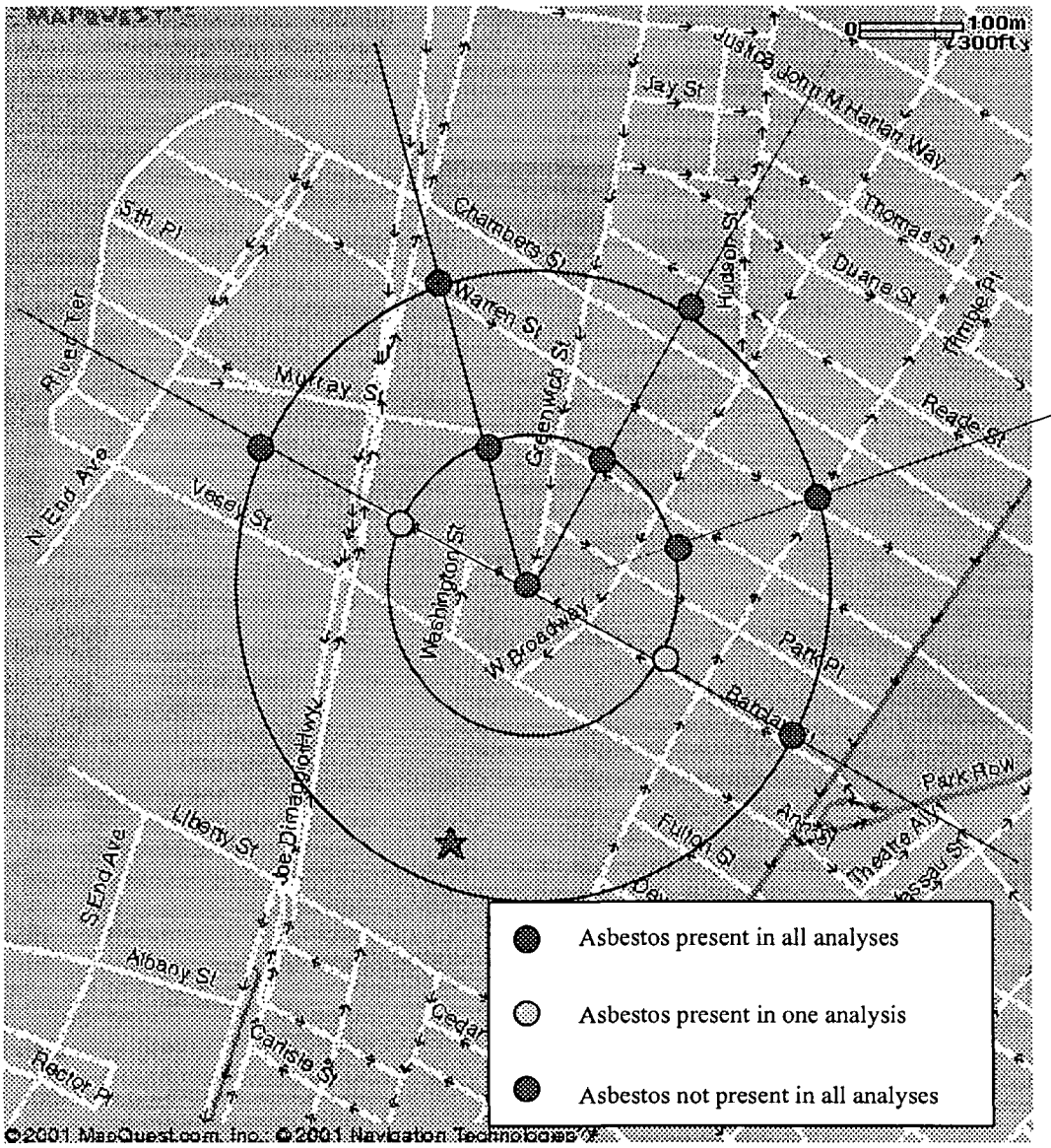

Figure 7. Histogram of asbestos fiber widths observed for samples analyzed using direct preparation methods. The fiber distribution is dominated by ultra thin fibers with 95% of all fibers less than 0.25 μm in width.

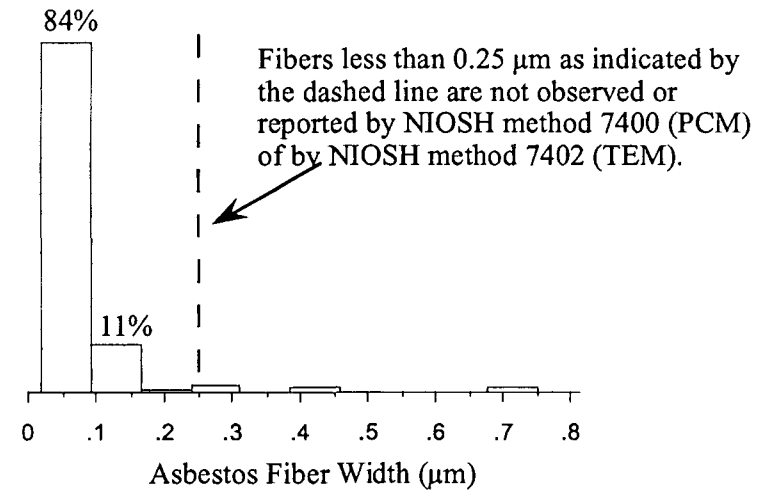

Figure 8. Histogram of asbestos fiber widths observed for samples analyzed using indirect preparation methods. The fiber distribution is dominated by ultra thin fibers with 96% of all fibers less than 0.25 μm in width.